APPLICATION OF VOLTAGE-TUNABLE META-MATERIALS IN PHASED-ARRAY ANTENNAS

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- FERROELECTRIC LENS
- PHASED ARRAY CONFIGURATIONS
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INTRODUCTION

- SINCE PHASED ARRAY ANTENNAS CAN SCAN THE BEAM BY ELECTRONIC MEANS (WITHOUT MOVING PARTS), THEY ARE DESIRED FOR MANY APPLICATIONS
- BUT PHASED ARRAY ANTENNAS ARE EXPENSIVE
- A NOVEL PHASED ARRAY IS BEING DEVELOPED THAT REDUCES THE COST OF PHASED ARRAY ANTENNA BY REDUCING THE NUMBER OF PHASE SHIFTERS, DRIVERS AND CONTROLS
- THE NOVEL ANTENNA USES FERROELECTRIC CERAMICS AND SO IT IS CALLED THE FERROELECTRIC LENS

FERROELECTRIC MATERIALS

- **FERROELECTRICS ($BaSrTiO_3$) HAVE THE UNIQUE CHARACTERISTIC OF A VOLTAGE TUNABLE DIELECTRIC CONSTANT**
  - **THIS PROPERTY CAN BE USED TO DEVELOP PHASE SHIFTING DEVICES**
- **HIGH DIELECTRIC CONSTANT AND LOSS TANGENT OF FERROELECTRICS HAVE LIMITED THEIR APPLICATIONS IN PHASED ARRAYS**
  - **$\varepsilon_r > 1000$ AND $\tan\delta > 0.014$ AT X-BAND**
- **RECENTLY DEVELOPED COMPOSITES ($BaSrTiO_3$ + MgO OR OTHER DOPANTS) HAVE LOWER DIELECTRIC CONSTANT AND LOWER LOSS TANGENT AT ROOM TEMPERATURE**
  - **$\varepsilon_r \sim 100$ AND $\tan\delta \sim 0.008$ AT X-BAND, TUNABILITY ~ 20% (Tunability is the fractional change in the dielectric constant)**
- **IT IS DESIRABLE TO FURTHER REDUCE THE DIELECTRIC CONSTANT AND LOSS TANGENT/TUNABILITY RATIO**

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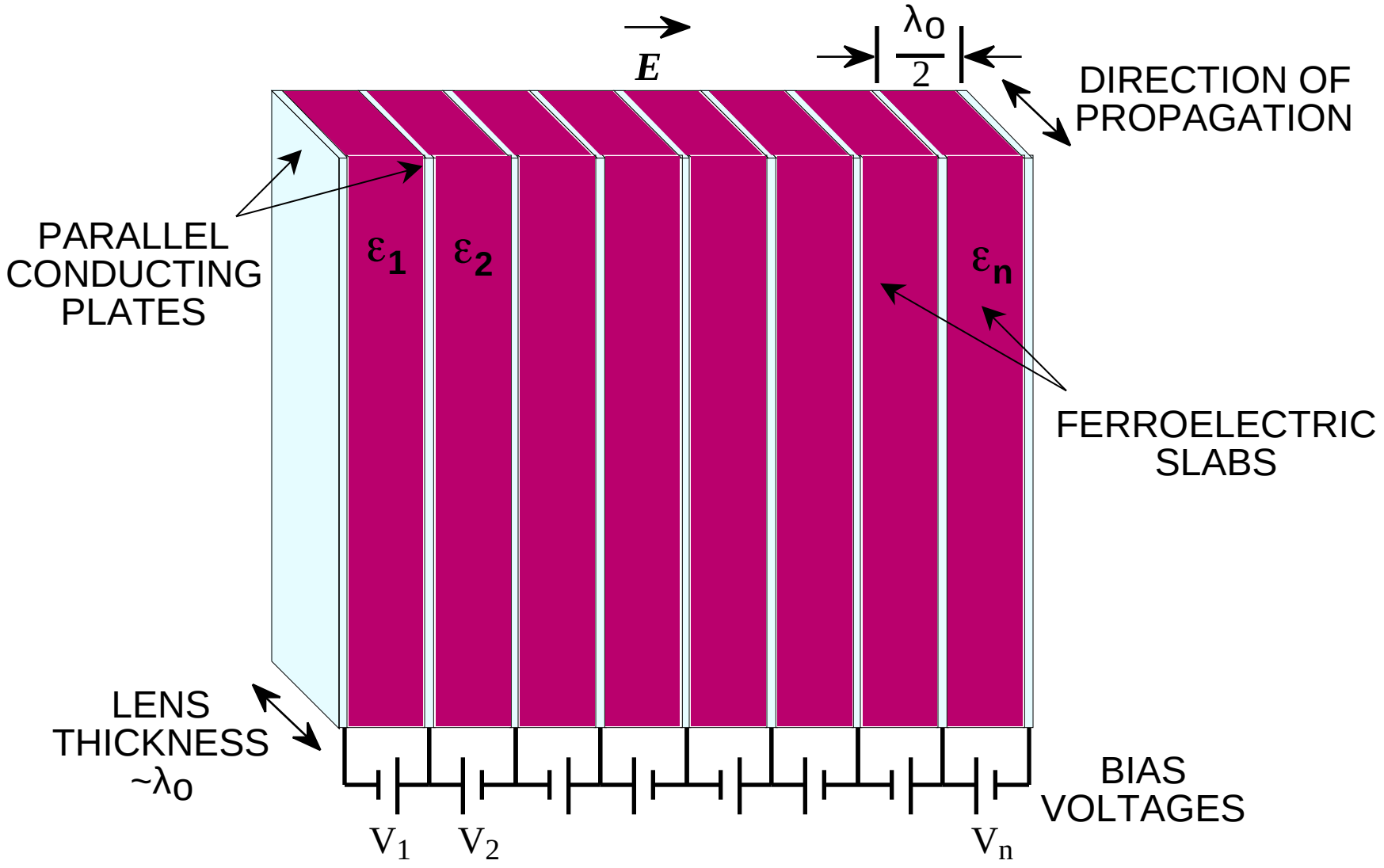
FERROELECTRIC LENS (Simplified Concept)



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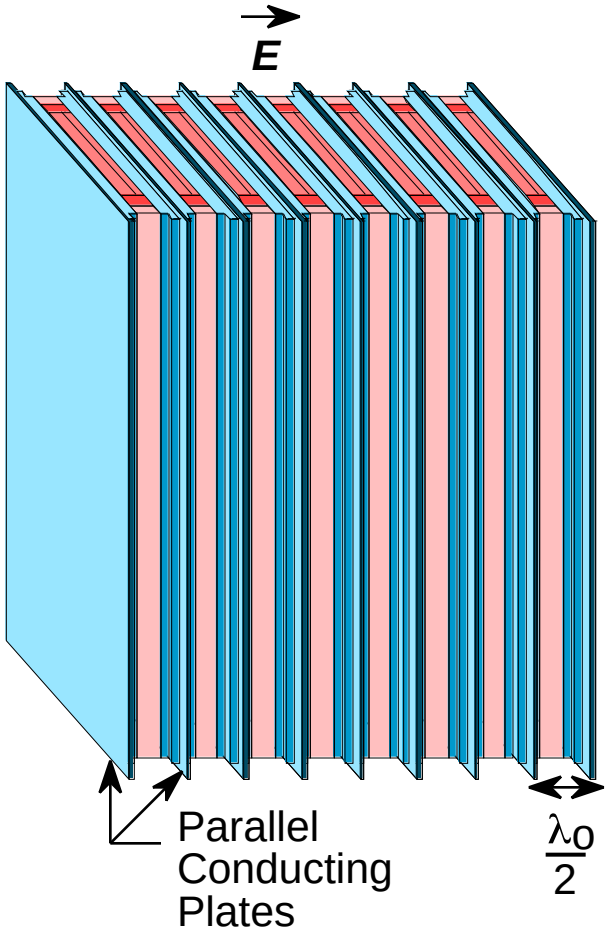
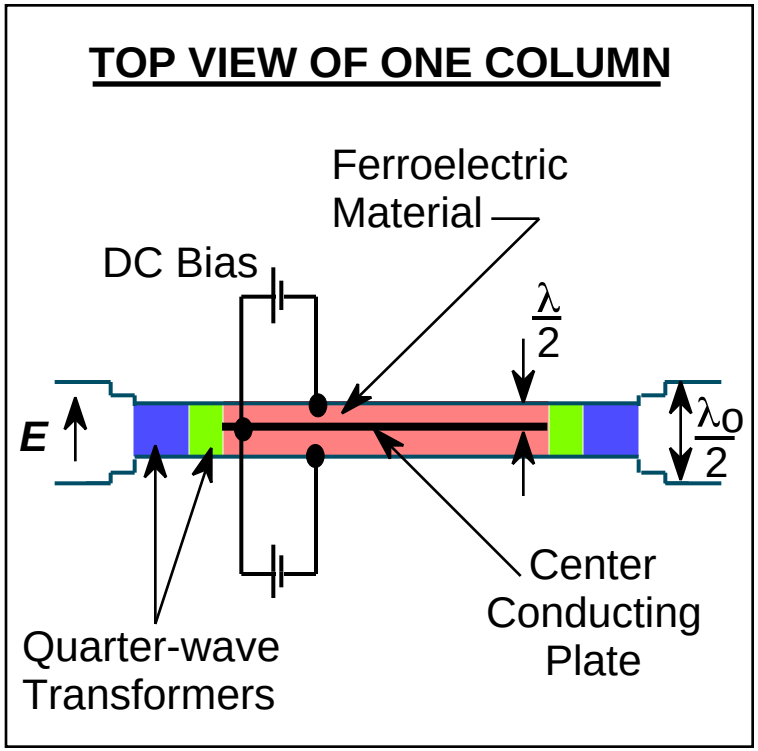
FERROELECTRIC LENS

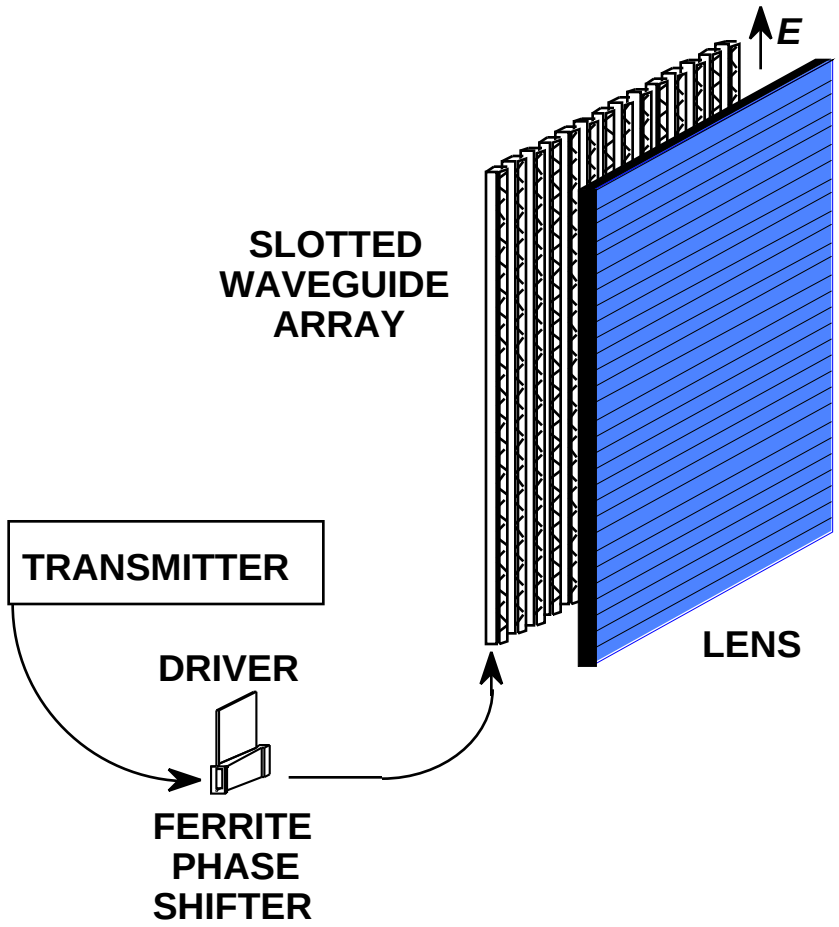




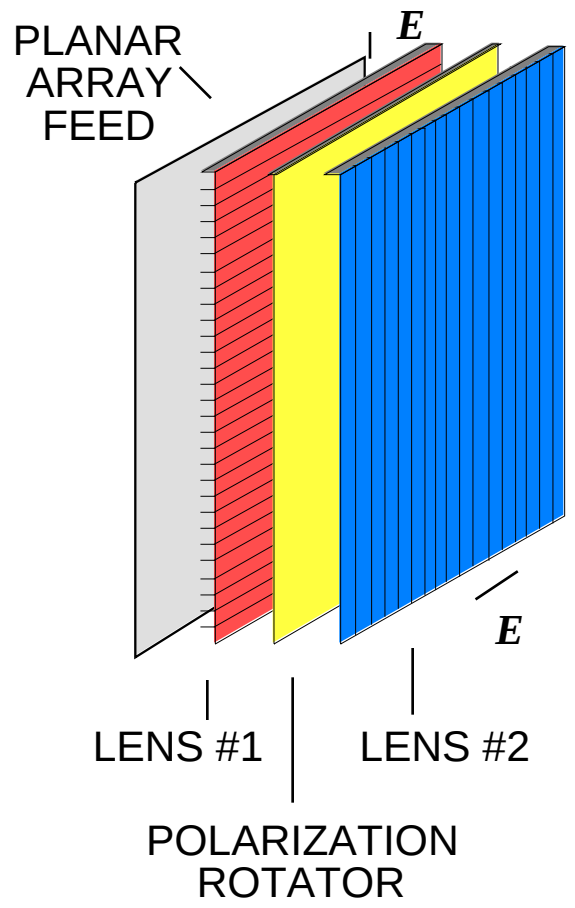
PERMITTIVITY IS A FUNCTION OF THE DC ELECTRIC FIELD

2-D PHASED ARRAY CONFIGURATIONS

HYBRID CONFIGURATION



DUAL LENS CONFIGURATION



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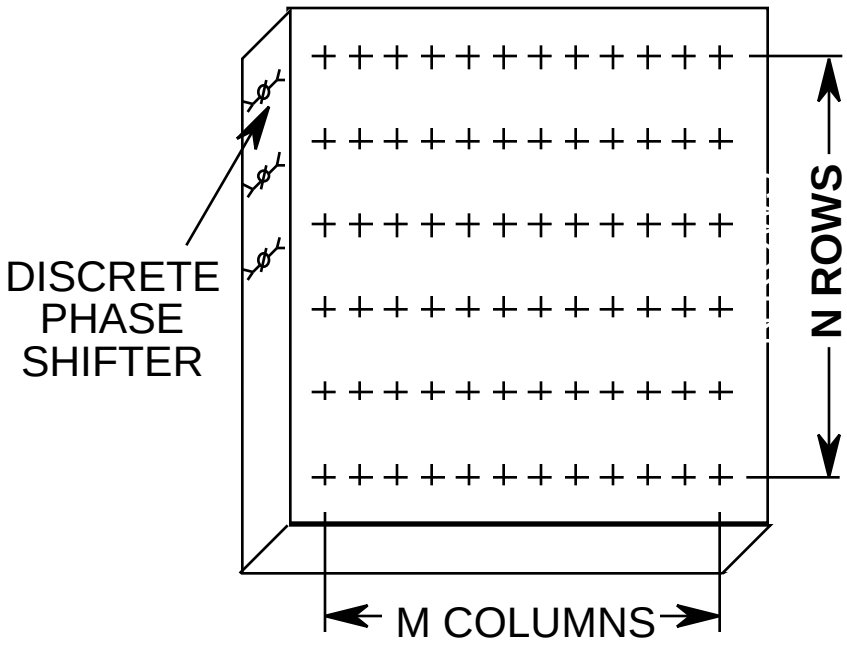
CONVENTIONAL VS. FERROELECTRIC LENS PHASED ARRAY

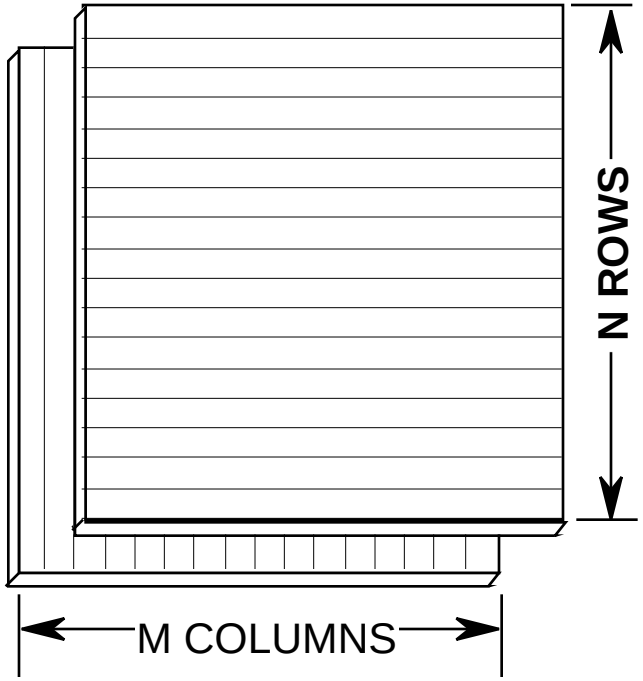
CONVENTIONAL LENS



OF PHASE SHIFTERS = M X N
OF DRIVERS = M X N

FOR M = N = 100, M X N = **10,000**

FERROELECTRIC LENS



OF PHASE SHIFTERS = M + N
OF DRIVERS = M + N

FOR M = N = 100, M + N = **200**

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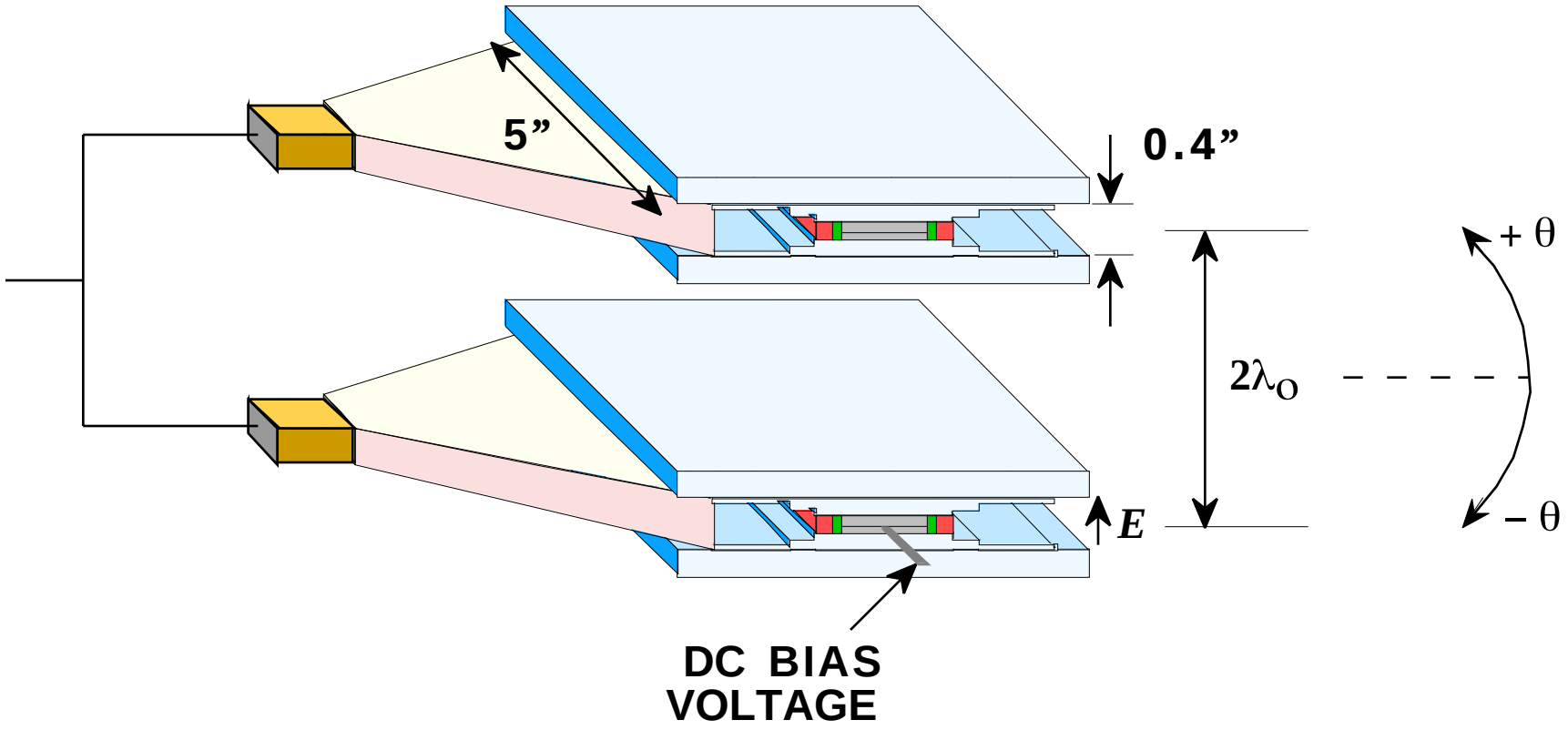
X-BAND 2-COLUMN INTERFEROMETER



RADIATION PATTERN IS MEASURED AS BIAS VOLTAGE IS APPLIED TO ONE COLUMN

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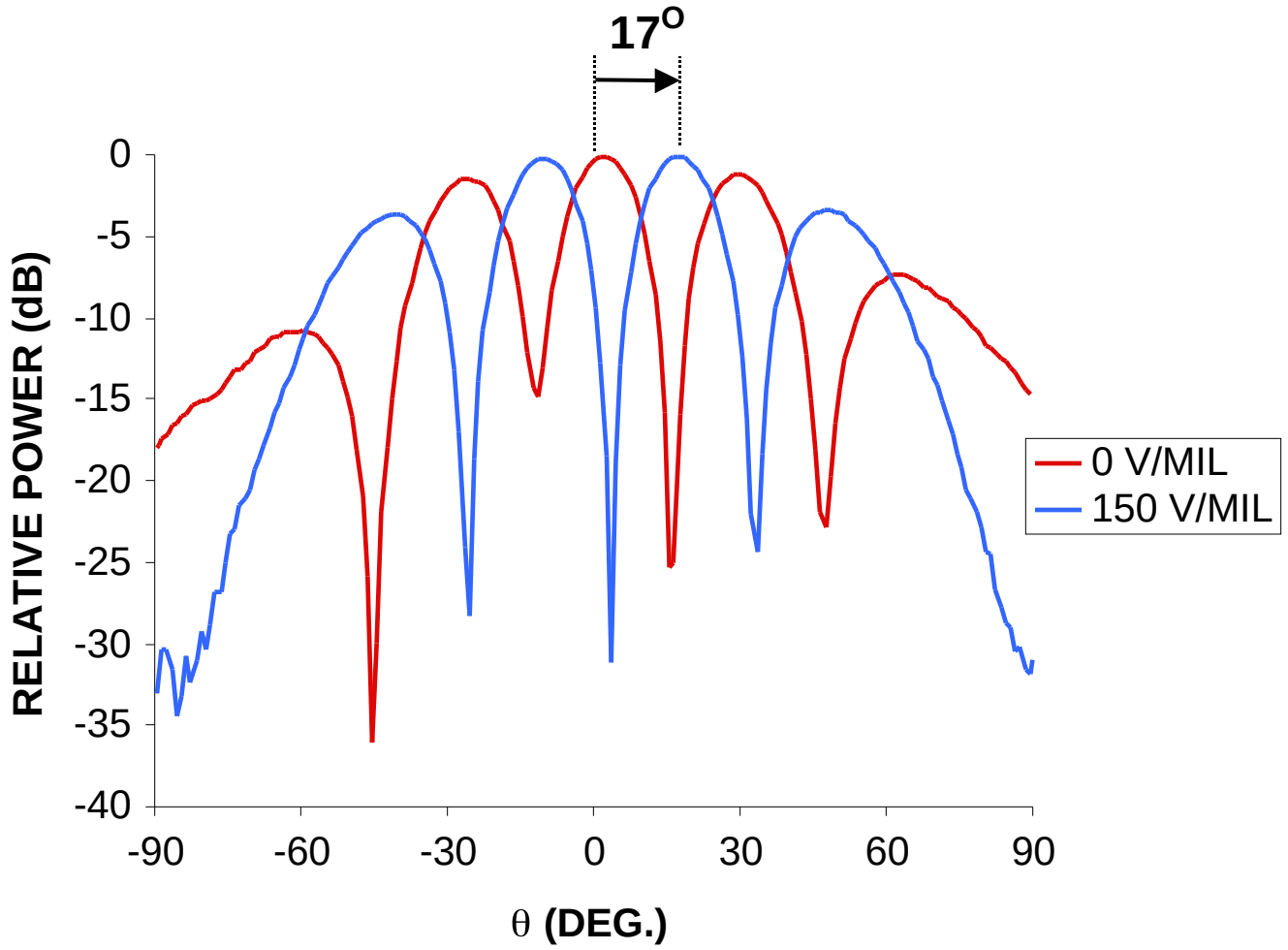
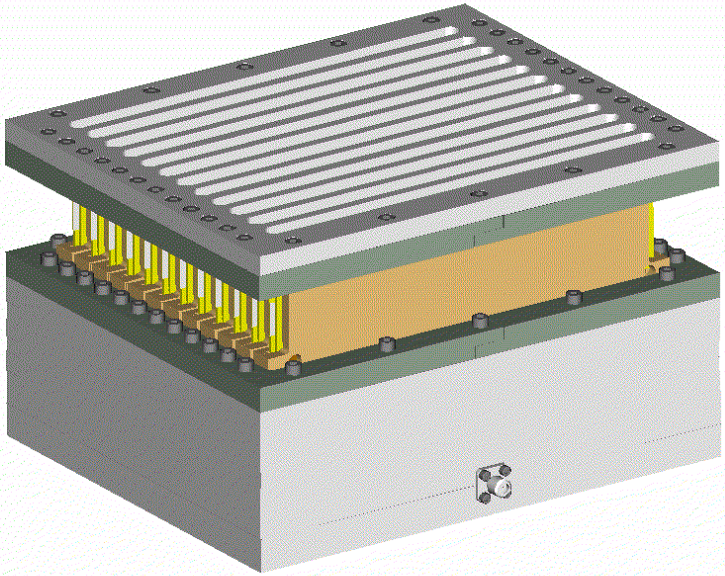
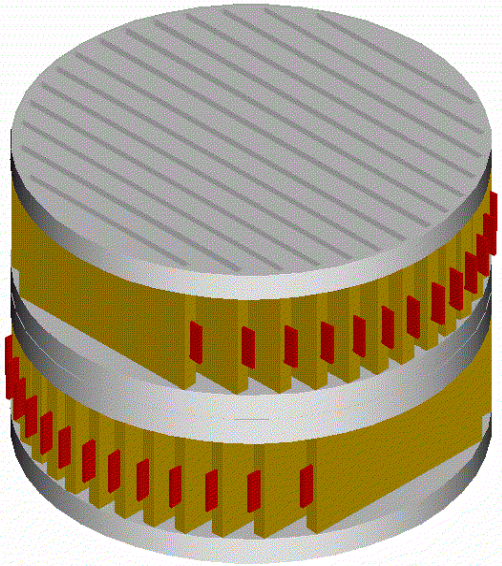
2-COLUMN INTERFEROMETER ANTENNA PATTERNS AT 10 GHz

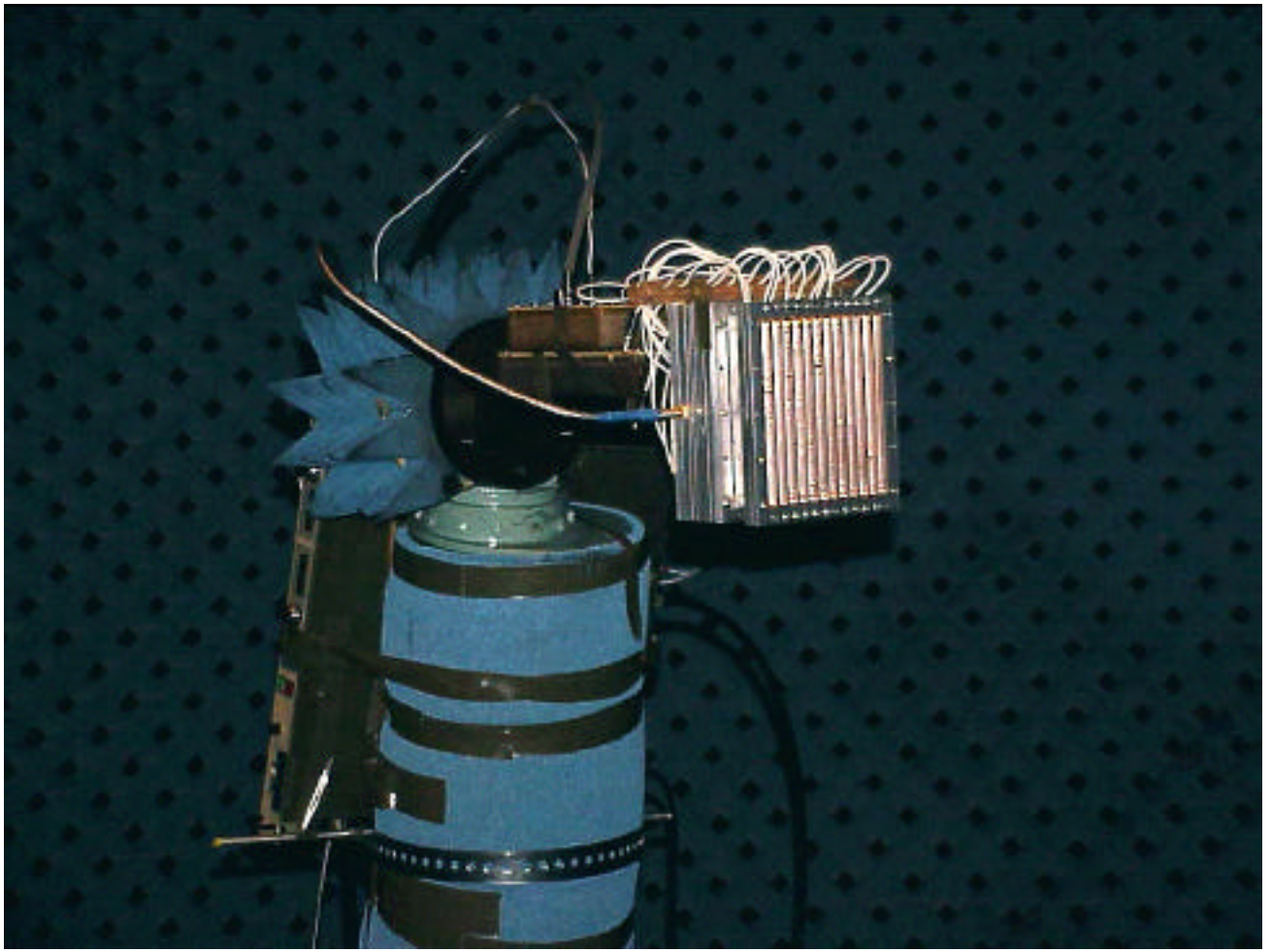


FERROELECTRIC LENS FOR MISSILE SEEKER





LENS PROTOTYPE UNDER TEST



LENS DESIGN PARAMETERS

$$\text{Voltage-Tunable Dielectric Loss (dB)} = 27.3\sqrt{\varepsilon_r}\,(\tan\delta)\,\frac{d}{\lambda_o}$$

$$360^o \text{ phase shift requires : } \frac{d}{\lambda_o} = \frac{1}{\sqrt{\varepsilon_{r(max)}} - \sqrt{\varepsilon_{r(min)}}}$$

$$\text{Tunability} = \frac{\varepsilon_{r(max)} - \varepsilon_{r(min)}}{\varepsilon_{r(max)}}$$

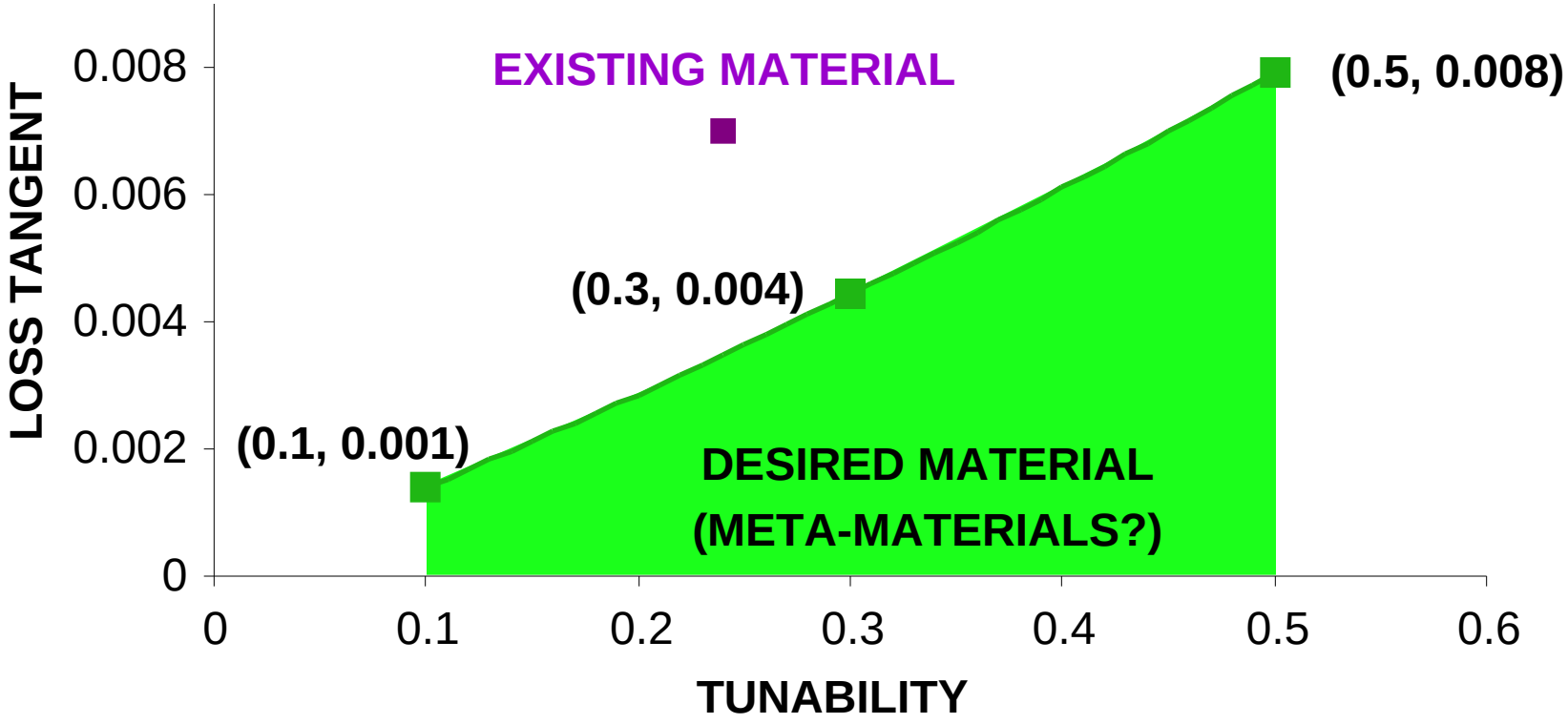
$$\text{For } 360^o,\ \text{Voltage-Tunable Dielectric Loss (dB)} = \frac{27.3\,(\tan\delta)}{1-\sqrt{1-\text{Tunability}}}\ \frac{55\,(\tan\delta)}{\text{Tunability}}$$

REDUCE tan δ / tunability RATIO TO IMROVE THE MATERIAL FIGURE-OF-MERIT

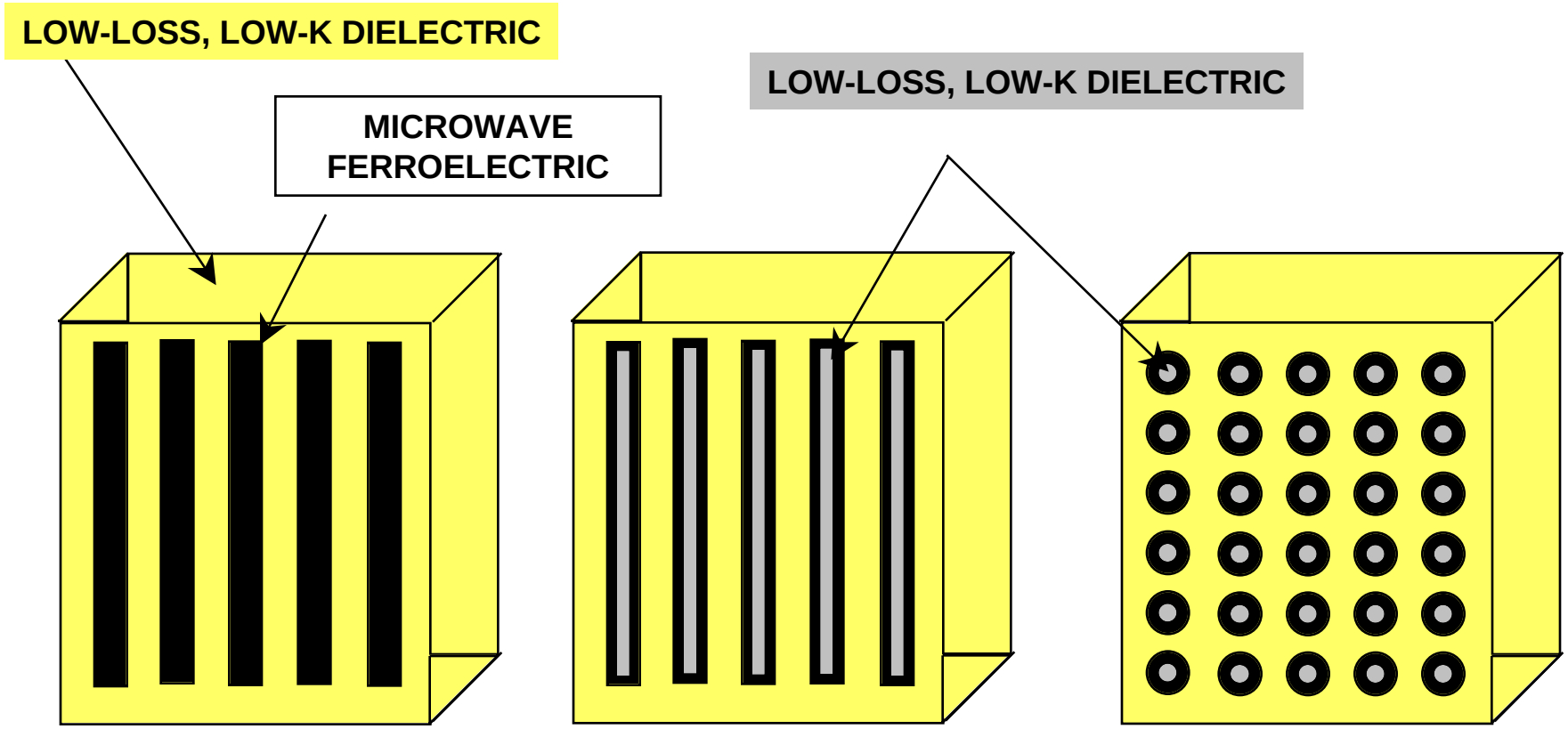
REDUCE DIELECTRIC CONSTANT FOR IMPEDANCE MATCHING

MATERIAL REQUIREMENTS

COMPOSITE LOSS TANGENT AND TUNABILITY NEEDED TO LIMIT LOSS TO 1 dB FOR 360° PHASE SHIFT



CONCEPTS FOR LOW-DIMENSIONAL, VOLTAGE-TUNABLE ENGINEERED COMPOSITES



FERROELECTRIC 1-3 COMPOSITE
Example: US Patent # 5830591
ARL & NRL

FERROELECTRIC 2-2-3 COMPOSITE
Example: US Patent # 5607631
Raytheon (Hughes)

FERROELECTRIC 1-1-3 COMPOSITE
Example: US Patent # 5607631
Raytheon (Hughes)

SUMMARY

- NRL HAS DEVELOPED AND DEMONSTRATED THE FERROELECTRIC LENS CONCEPT FOR AFFORDABLE PHASED ARRAYS
- CURRENT MATERIAL LOSS IS ABOUT 2 dB AT X-BAND
- DARPA FAME PROGRAM IS FUNDING MATERIAL IMPROVEMENT FOR CONVENTIONALLY ENGINEERED CERAMIC COMPOSITES
- LOW-DIMENSIONALLY ENGINEERED COMPOSITES MAY OFFER THE DESIRED MATERIAL PROPERTIES
  - REDUCED tan d / tunability RATIO TO IMPROVE THE MATERIAL FIGURE-OF-MERIT
  - REDUCED DIELECTRIC CONSTANT FOR IMPEDANCE MATCHING
  - META-MATERIALS HOMOGENEITY AND ISOTROPY AT MICROWAVE FREQUNCIES ARE CRITICAL FOR PHASED-ARRAY APPLICATIONS